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Evaluation of a Standardized Spatial Disorientation Flight Profile

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This study was designed to examine the feasibility of using visual-vestibular mismatch software to produce disorienting events in flight within a standardized simulator flight profile. Data were examined in order to ensure that collection of standard flight performance measures was not interrupted by the addition of disorienting events. Twenty-one UH-60 qualified Army aviators flew a 1-hour UH-60 simulator flight profile containing three visual-vestibular mismatch events (visual and vestibular divergence used, 4 degrees per sec with pitch, 6 degrees per sec with roll, and 8 degrees per sec with drift). Following the flight, aviators filled out a simulator sickness questionnaire and rated each event in terms of difficulty of aircraft control recovery. Evaluation of the data showed that the divergence rates were enough to produce spatial disorientation in the aviators, but were not severe enough to produce total disorientation resulting in crashed aircraft (no aviator crashed the simulator as a result of the events) or simulator sickness. Thus, it appears that this flight profile can be used as a new tool to test the effects of various stressors (i.e., heat, cold, and fatigue) on aviator response to disorientating events in flight without putting the aviator at risk.

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Introduction

The primary purpose of this investigation was to establish a standardized simulator flight profile that could be used to collect and analyze flight performance measures during tests of pilot response to disorienting events. This 1-hour profile contained repeated measures of standard flight maneuvers that included straight and level flight, standard rate turns, hovers, and descents. The flight profile also contained three visual-vestibular mismatch events designed to produce disorientation. All flight performance data were recorded and examined to ensure that disorientation software did not interfere with normal data collection and retrieval processes. Subjective and objective measures of flight parameter recovery following the visual-vestibular mismatches and symptoms of simulator sickness produced by this flight profile were examined.

Background

Spatial disorientation (SD) occurs in flight when a pilot fails to correctly sense the position, motion or attitude of his/her aircraft or self with respect to the surface of the earth (Kraus, 1959). Such misperceptions can have disastrous effects as summarized in retrospective studies of U.S. Army helicopter accidents involving SD (Durnford et al., 1995; Braithwaite, Groh, and Alvarez, 1997). In the most current review, Braithwaite, Groh, and Alvarez (1997) reported that SD was a major or contributory factor in 30 percent of all class A through C accidents. Comparisons by these authors have shown that the outcomes of accidents involving SD were much more severe than those not involving SD. During the period 1987-1995, 36 percent of SD accidents were Class A compared to 18 percent of non-SD accidents. The average monetary cost of the SD accidents was more than double ($1.62 million) that of non-SD accidents ($0.74 million), as was the loss of life per accident (0.38 versus 0.14).

In a recent survey of U.S. Army rotary-wing aircrew, 78 percent of the respondents reported suffering SD to some degree during their careers (Durnford et al., 1996). While the percent of pilots having reported an SD experience in this study was quite high, other surveys have reported career incidents ranging from 90-100 percent (Eastwood and Berry, 1960; Clarke, 1971; Tormes and Guedry, 1974; Steele-Perkins and Evans, 1978; Durnford, 1992). As SD appears to be a very common and very costly aviation phenomenon, the British Army began using a spatial disorientation training sortie in 1982. According to Braithwaite (1997), the SD accident rate in the British Army Air Corps has dropped significantly since the inception of this training program. During the period 1971-1982 (prior to sortie training), pilots averaged 2.04 accidents per 100,000 flight hours. This rate dropped to 0.57 accidents per 100,000 flight hours following the onset of the SD training (1983-1993). Unfortunately, changes in aircraft, crew composition (from single pilot to two pilot crews) and instrumentation (radar altimeters) also occurred during this time frame (mid 1980's). These confounding factors make it difficult to apportion the decrease in SD accidents to improved training or improved aircraft.

In addition to training, Braithwaite et al. (1998) examined the use of a novel display to assist in overcoming disorienting phenomenon. These researchers tested recovery from unusual attitudes using a flat panel display designed to reduce cognitive workload and improve flight accuracy. Subjects in this protocol were required to close their eyes while the computer put them in an unusual attitude from which they attempted to recover. The novel display was quite successful in enhancing flight control and aiding in recovery from the disorienting episodes. While this study provided much useful information about recovery from disorienting episodes, it was not designed to examine the detection of a disorienting event inflight. During real flight, pilots would not be given a warning that a disorienting event was about to occur. Thus, to obtain data that could be generalized more easily to actual in-flight occurrences of spatial disorientation, a more realistic simulator flight profile needed to be developed and tested.

Methods

Flight profile design

The U.S. Army Aeromedical Research Laboratory possesses specially designed computer software that allows the NUH-60 Blackhawk simulator to perform maneuvers that other UH-60 simulators cannot. Using this software, our simulator operators can produce divergent visual and motion cues. These visual-vestibular mismatches often result in SD as pilots are unable to correctly sense their position, motion, or aircraft attitude. While it was fairly easy to execute the divergence of visual and motion cues, their effectiveness over different terrains had not been established.

Working closely with USAARL's research aviators, a 1-hour flight profile was designed incorporating standard maneuvers over varying terrain such as water, mountains, and forest. Several of our pilots flew the course and picked 12 sites where the mismatches would be most effective at producing SD. Additionally, 12 possible combinations of visual and vestibular mismatches were identified. After testing the different types of mismatches (e.g., visuals left, motion right; visual up, motion down) at various sites along the flight path, two sets of three (A and B) were chosen. A description of the flight profile and the mismatches are presented in a table on page 6. During development of the profile, data collection, retrieval, and analyses procedures were established as no methods previously existed. The Research Systems Branch designed a method to tag the onset of and recovery from the mismatches in the continuous binary data streams. Recovery was defined as the point in time at which a pilot returned to the heading, altitude, and airspeed being flown immediately prior to the event. A special scoring routine was developed to calculate these reaction times.

Subjects

Twenty-one UH-60 qualified Army aviators flew a 1-hour standardized UH-60 simulator flight profile containing three visual-vestibular mismatch events. Two sets of mismatches, A and B, were used. These sets contained mirror opposite mismatches. For example, if profile A had a pitch event where visuals went up and motion went down, then profile B had a pitch event where visuals went down and motion went up. Ten aviators flew profile A and 11 aviators flew profile B. Informed consent was obtained from each volunteer prior to participation. Following each flight, the aviator was asked to fill out a simulator sickness questionnaire. Aviators were also asked to rate each SD episode in terms of difficulty of aircraft control recovery.

Apparatus

UH-60 simulator

All simulator flights were conducted in the NUH-60 flight simulator that includes computer-generated visual displays and a multi-channel data acquisition system for analyzing various parameters of flight such as heading, airspeed, and altitude control. Digitized flight performance data were collected and stored on a VAX computer system for subsequent statistical evaluation.

Simulator sickness questionnaire

At the end of each flight, the aviator completed a Simulator Sickness Questionnaire (Gower and Folkes, 1989). This instrument is a self report form consisting of 27 symptoms that are rated by the participant either as being present or absent or in terms of severity on a 4-point scale. These data were collected to assess motion sickness symptom severity. It was not anticipated that this flight profile would be more provocative than normal simulator flight profiles; however, as these symptoms may adversely affect flight performance these data were collected.

Spatial disorientation questionnaires

Following the flight, aviators were asked to assess recovery from each of the SD events. The SD questionnaire consisted of three 100 mm lines centered over the event number (1-3). At the ends of each line, “extremely easy” and “extremely difficult” were printed, respectively. Scores consisted of the distance from the left end of the line to the pilot’s mark in mm.

Procedure

General

The flight evaluations required pilots to perform a variety of precision maneuvers typically flown in a UH-60 (see table). This flight profile consisted of low-level navigation to five checkpoints and upper-airwork in which the aviators were required to perform precision maneuvers primarily based upon instrument information. Three SD events occurred during the flight. As the majority of SD accidents occur at night (Braithwaite et al., 1997), all flights were flown under simulated dusk conditions regardless of the actual time of day. Each flight was coordinated and controlled by the same simulator operator, who instructed the aviators through the standardized maneuvers in a uniform fashion. Because coaching may influence subjects' behavior in unpredictable ways, the simulator operator did not provide any feedback to pilots regarding the accuracy of performance, the procedures used, or specific or general techniques designed to improve or in any way change performance. The simulator operator avoided answering specific questions asked by aviators about their performance or technique by stating that they would provide the subject with a full debrief at the end of the study.

Flight profile

The flight profile simulated a UH-60 flying a mail delivery route which included stops at several remote sites. An onboard simulator operator provided frequent cuing to the subject-pilot throughout the profile to ensure proper timing and standardization of the flight maneuvers, and marked the beginning and ending point of each individual maneuver for the purpose of delimiting subsequent computer maneuver analysis. The entire profile took approximately 60 minutes to fly.

There were a total of 27 tasks, containing 10 standardized flight maneuvers, in the flight profile. These maneuvers consisted of one stationary hover, one 180^0 hovering turn, two standard-rate climbs, two standard-rate turns, two straight-and-levels, and two standard-rate descending turns. During each of the maneuvers, excluding the stationary hover and hovering turn, the aviators were required to maintain an airspeed of 120 knots. The specific targets for other parameters such as heading, altitude, roll, slip, etc., changed depending upon which maneuver was being flown. Aviators attempted to maintain appropriate ideal flight parameters during each maneuver.

Spatial disorientation events

Each pilot experienced three SD events during the flight. The events were terrain specific and occurred at the same point for each set of aviators. The rates of visual and vestibular divergence used during these events were considered slow to medium and should not have posed perceptual problems which persist following flight termination (personal communication from COL M. Braithwaite).

Profile A

Event #1 occurred during task 11. This was a pitch event where the visuals moved up and motion moved down at a 4^0 per sec divergence. This event occurred during low level flight and gave the impression that the aircraft was nosing into the ground. Event #2, a roll, occurred during task 15. Visuals rolled right and motion rolled left at a 6^0 per sec divergence. This event occurred as each aviator flew over hilly terrain and was designed to give the impression that the aircraft was rolling right, into a hill. Event #3 was a drift. As each aviator began to land during task 21, visuals moved left and motion moved right at an 8^0 per sec divergence causing an apparent aircraft drift.

Profile B

While the three events in profile B were opposite those in profile A, the rates of divergence were held constant between profiles. In profile B, event #1, a roll, occurred during task 9 where visuals rolled left and motion rolled right. Event #2 was a drift. As each aviator began to land during task 13, visuals moved right and motion moved left. Event #3 was a pitch event where visuals moved down and motion moved up.

Data collection

The computer calculated root mean square (RMS) errors for a variety of measures within each of the flight maneuvers in order to express how well subjects maintained specific headings, altitudes, airspeeds, and other parameters. The computer time-stamped the onset of each SD event. Following the onset of each event, the simulator operator instructed the pilot to recover to the original course heading, altitude and airspeed. When these criteria were met, the simulator operator time-stamped the data stream. In the case of a drift event during landing, the pilot was instructed to establish a 10 foot stabilized hover over the landing point on the original heading.

Table
Flight profile.

Task #	Description	Time (SEC)	Heading (DEG)	Altitude (FEET)	Airspeed (KIAS)	Profile A	Profile B
1	Hover	60	090	10' AGL	0		
2	Hovering Turn	60	090>090	10' AGL	0		
3	Low Level Navigation	240	086	700' MSL	120		
4	Climb	60	100	700>1200' MSL	120		
5	Right Standard Rate	60	100>280	1200' MSL	120		
6	Straight and Level	60	280	1200' MSL	120		
7	Descending Right Turn	60	280>100	1200>700' MSL	120		
8	Nap of the Earth	180	344	25' AGL	120		
9	Contour	180	031	80' AGL	120		Event 1
10	Landing	120	015	N/A	N/A		
11	Nap of the Earth	240	338	25' AGL	120	Event 1	
12	Contour	120	296	80' AGL	120		
13	Landing	120	255	N/A	120		Event 2
14	Contour	240	319	80' AGL	120		
15	Contour	120	250	80' AGL	120	Event 2	
16	Climb	60	200	1000>1500' MSL	120		
17	Left Standard Rate Turn	60	200>020	1500' MSL	120		
18	Straight and Level	60	020	1500' MSL	120		
19	Descending Left Turn	60	020>200	1500>1000' MSL	120		
20	Contour	180	173	80' AGL	120		
21	Landing	120	215	N/A	N/A	Event 3	
22	Contour	240	066	80' AGL	120		Event 3
23	Contour	120	076	80' AGL	120		
24	Contour	120	181	80' AGL	120		
25	Contour	240	214	80' AGL	120		
26	Landing	120	180	N/A	N/A		
27	Nap of the Earth	240	249	25' AGL	120		

Profile A	Event 1 = Pitch	Event 2 = Roll	Event 3 = Drift
Profile B	Event 1 = Roll	Event 2 = Drift	Event 3 = Pitch

KIAS=Knots indicated airspeed, MSL=Mean sea level, AGL=Above ground level.

Data analysis

BMDP4V was used to conduct a series of analyses of variance (ANOVA) on reaction time, subjective flight performance, and simulator sickness data. The between-subjects factor was group (Profile A and Profile B). The within-subjects factor was SD event (3 levels: Pitch, Drift, and Roll). Significant interactions and main effects were followed up by analysis of simple effects and/or pairwise contrasts. Huynh-Feldt adjusted degrees of freedom were used when violations of the compound symmetry assumptions were observed. Correlations were also performed between each pilot's total number of flight hours and variables of interest such as reaction time to the SD events and subjective response to the events.

Flight performance

Each UH-60 flight was scored using specialized routines on USAARL's main computer system. RMS errors and other flight scores were calculated and stored for subsequent analyses. Several flight performance measures were collected for each of the maneuvers in the flight profile. These measures varied with the type of maneuver involved (i.e., it would not be reasonable to examine heading fluctuations in a turn maneuver). However, due to the nature of this study, flight scores were not statistically analyzed. Reaction time from the onset of the SD event to full flight control recovery was the primary measure used to examine the effects of SD on flight performance.

Simulator Sickness Questionnaire

A diagnostic scoring technique was applied to the checklist of the 27 symptoms that were rated by the participant resulting in scores on three subscales (nausea, visuomotor, and disorientation), in addition to a total severity score. For all scales, a score of 100 indicated absence of sickness. The total severity and subscale scores were analyzed.

Subjective flight evaluations

Subjective measures of the SD events that occurred during the flight profile were collected using a modified Visual Analog Scale (Penetar et al., 1993). Following administration of the simulator sickness questionnaire, each pilot marked on the line his/her feelings about the difficulty of flight recovery following each event.

Results

Objective recovery time

Analysis showed that there was no group effect or a group by event interaction indicating that reaction times to the SD events in Profiles A and B were equivalent. There was, however, a main effect for event ($F(2,38)=203.55$, $p<.001$). Contrasts showed that it took aviators significantly longer to recovery from the drift than from either the pitch or the roll. As illustrated in Figure 1, it took the aviators approximately 54 seconds to recover from the pitch and roll events but more than twice as long to recover from the drift event (122 seconds).

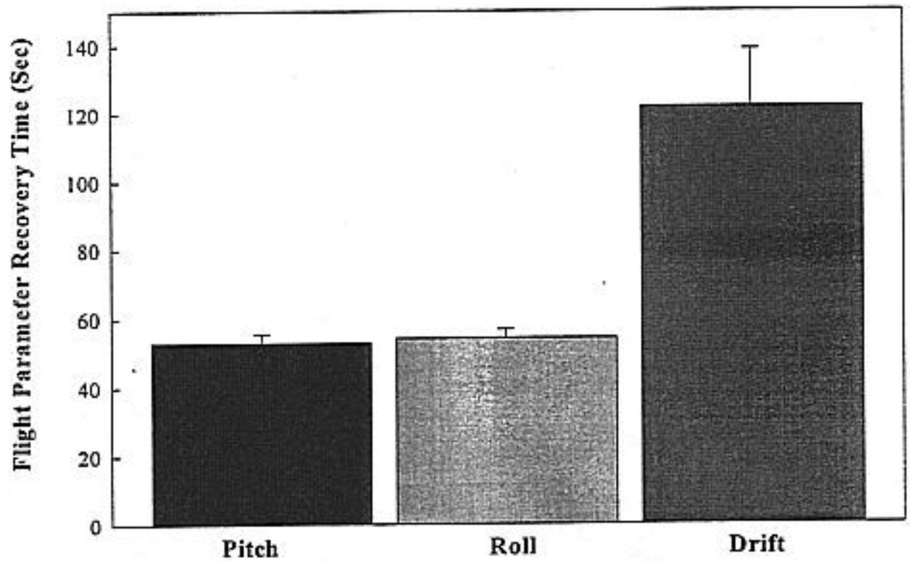

Figure 1. Effect of event type on recovery time.

Subjective recovery

Analysis of the pilots' self-ratings of difficulty of flight recovery following each SD event showed no group, event, or group by event interaction. These results (Figure 2) indicated that aviators considered recovery from all three of the SD events equally challenging.

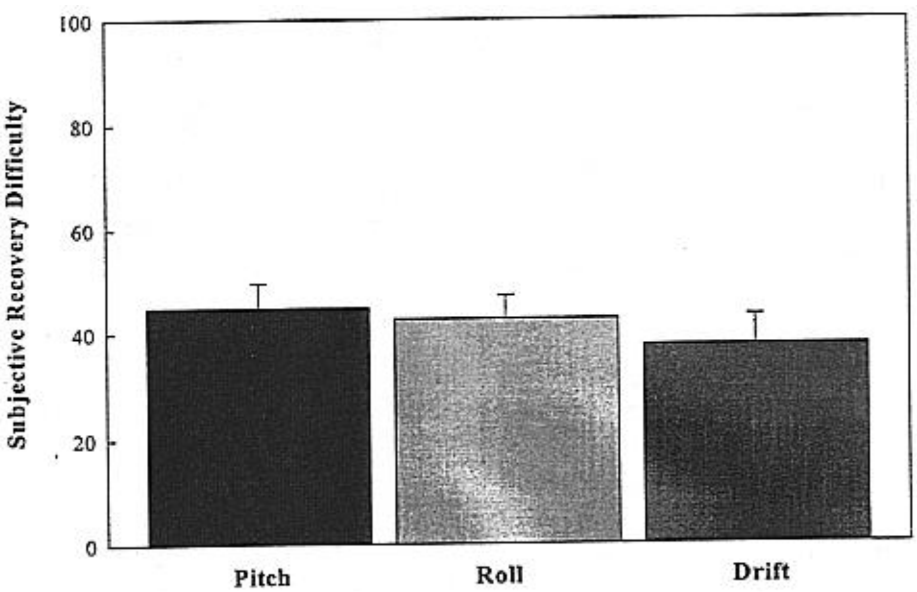

Figure 2. Effect of event type on self-rated recovery.

Objective recovery time versus subjective recovery difficulty

As illustrated in Figure 3 below, a slight but nonsignificant positive correlation was seen for objective and subjective measures of flight recovery following the pitch event (R=.216, p=.35). However, the regression lines for the roll and drift events are almost completely flat, demonstrating that actual performance and self-rated performance are poorly related (Roll R=.032, p=.89; Drift, R=.038, p=.87).

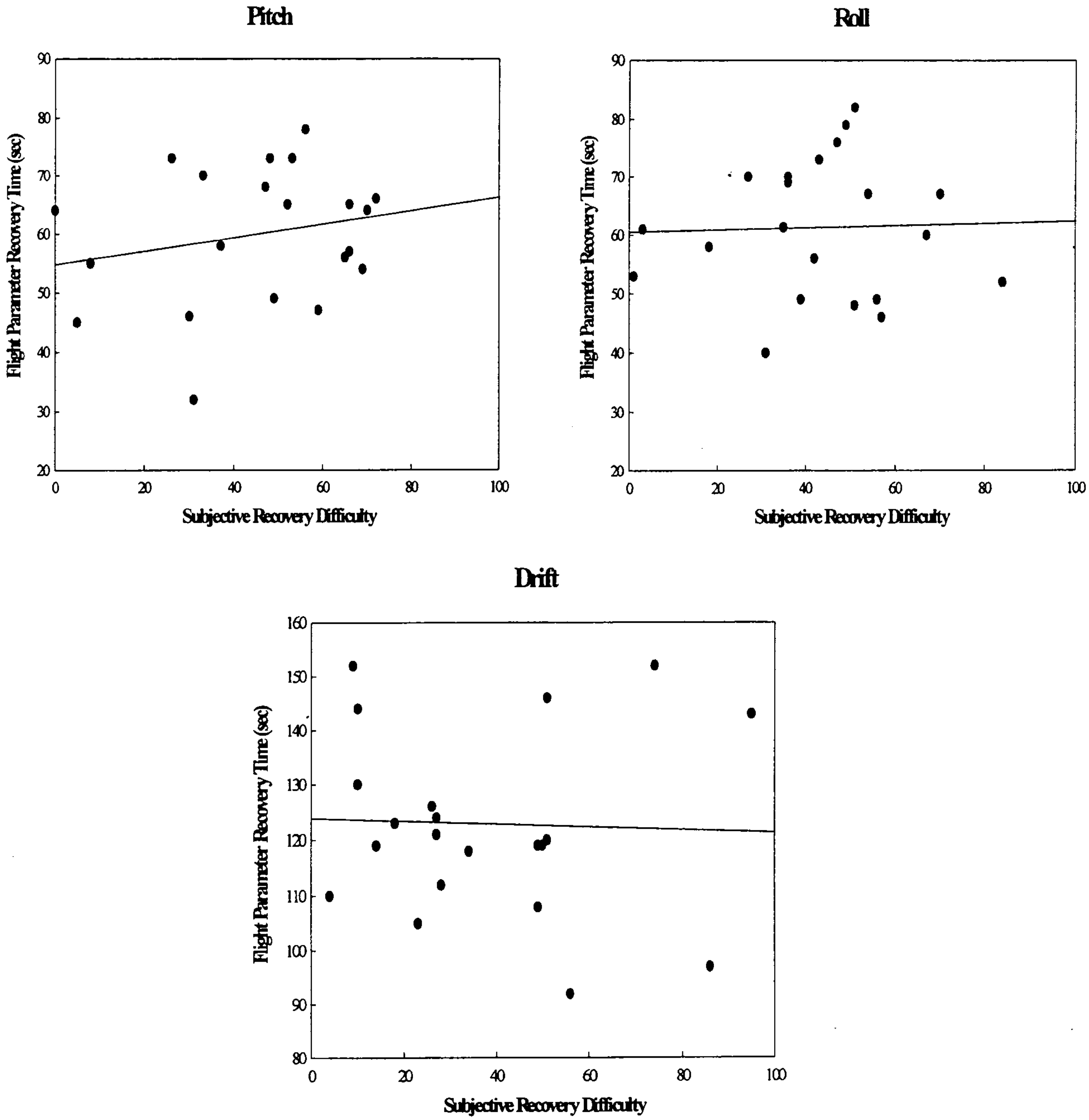

Figure 3. Correlation between objective and subject flight recovery for each event.

Objective recovery time versus total flight time

Correlations between total flight time and recovery time following the three SD events showed a complete lack of relationship between these measures (Pitch, R=.098, p=.67; Roll R=.0001, p=.99; Drift, R=.12, p=.60). As shown in Figure 4, the regression lines are almost completely flat with slopes near zero. The reaction times to full flight parameter recovery following the disorienting events were not faster in the most experienced pilots. These results show that even pilots with 8,000-12,000 hours of flight time are not impervious to the effects of spatial disorientation on performance.

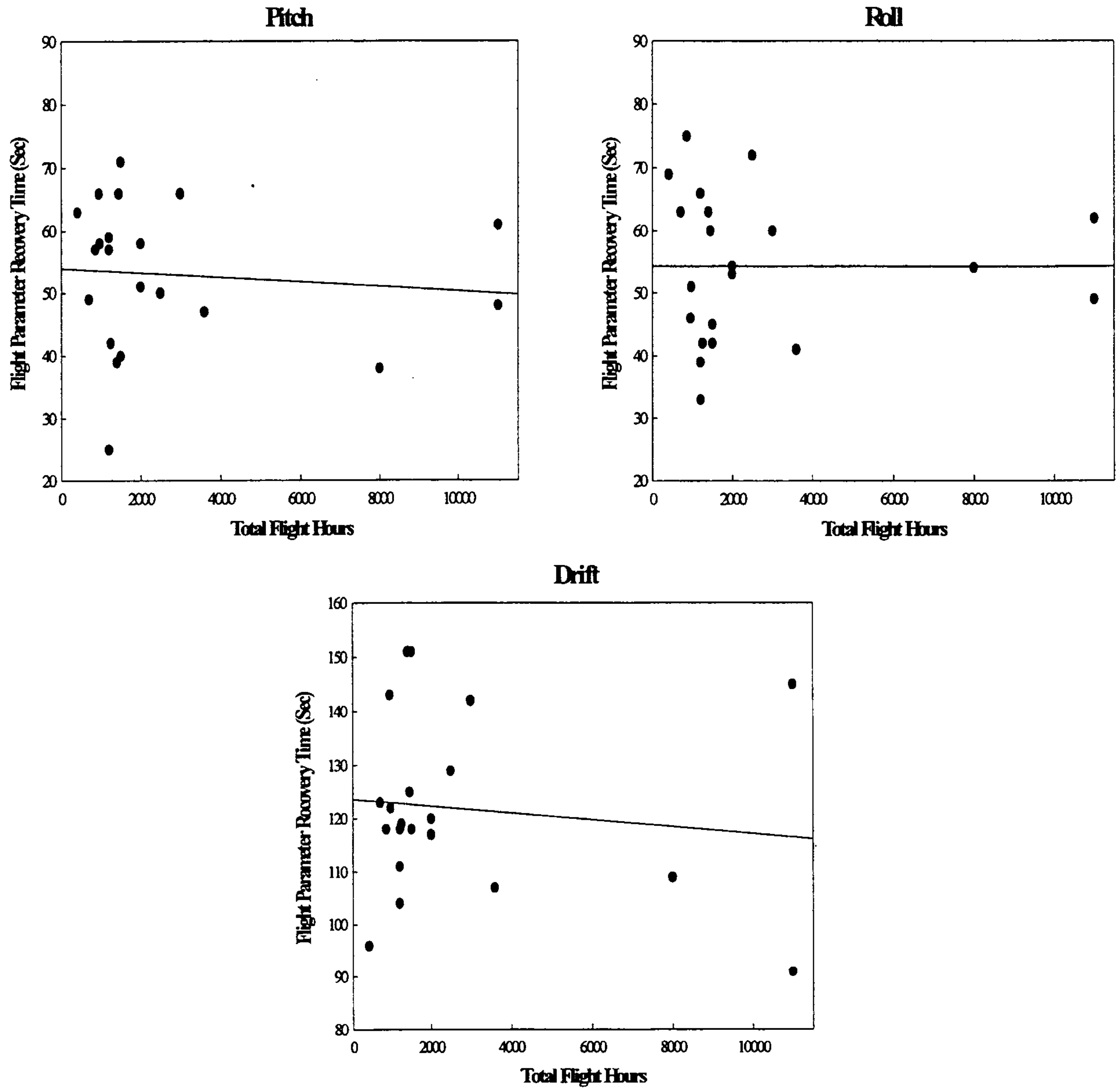

Figure 4. Correlation between total flight hours and objective recovery time for each event.

Subjective recovery time versus total flight time

Correlations between total flight time and the subjective responses to the SD events showed a slight but not significant (R=.38, p=.09) negative correlation between flight experience and the aviators self-rated difficulty recovering flight control in response to the pitch event. As shown in Figure 5, subjective difficulty of flight recovery following a pitch event decreased as flight experience increased. There was no correlation between flight time and the subjective responses to the roll or drift (Roll, R=.19, p=.41; Drift, R=.09, p=.69).

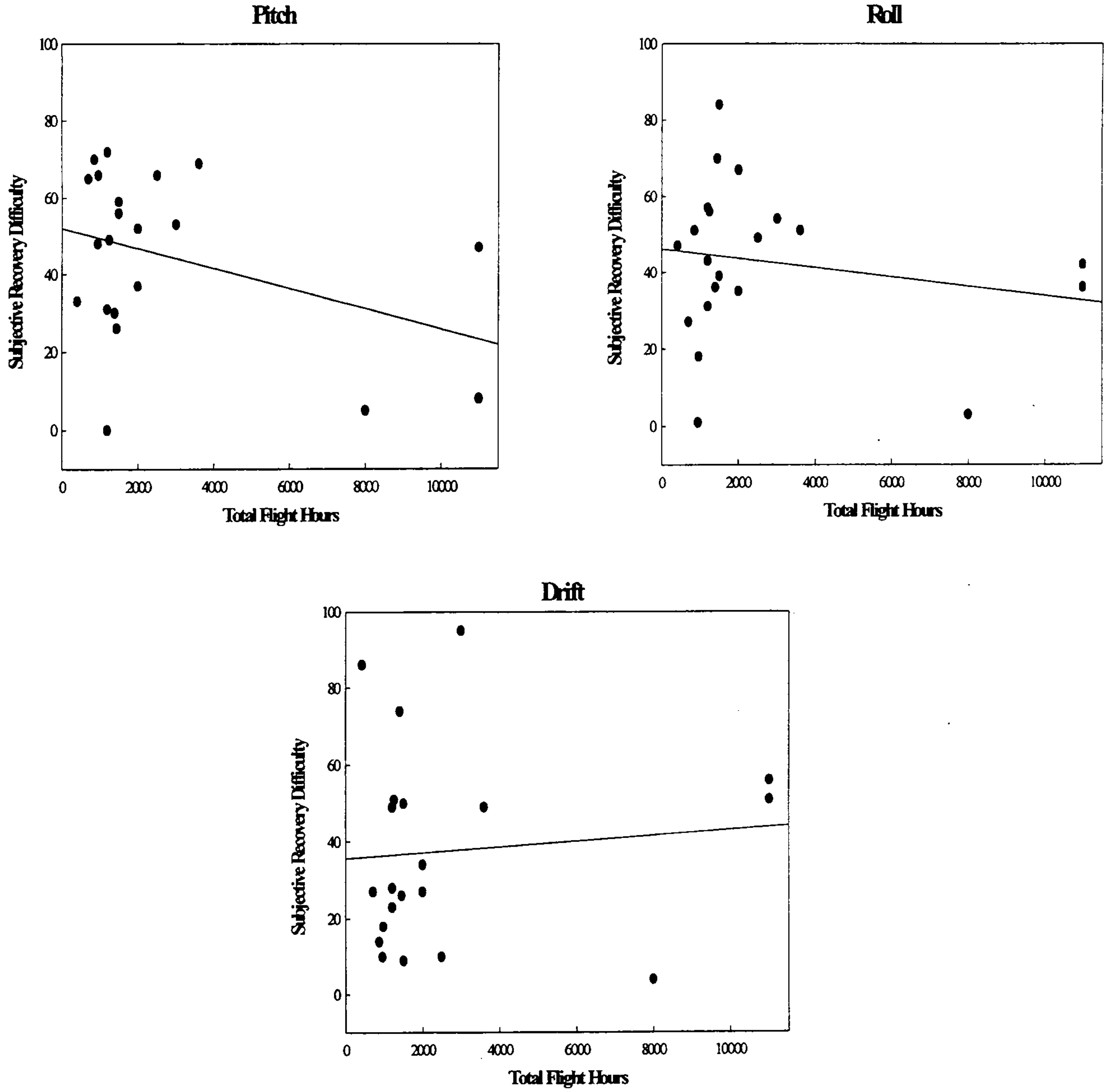

Figure 5. Correlation between total flight hours and self-rated recovery for each event.

Simulator Sickness Questionnaire (SSQ)

Analysis of the SSQ data showed that there was no group effect (Profile A or B) nor did this flight profile induce severe symptoms of simulator sickness (figure 6). For all scales, a score of 100 indicates a total absence of sickness. The standard deviation for this questionnaire is 15. According to Lane and Kennedy (1988), the developers of the SSQ, scores from 100 to 115 (0 to 1 standard deviation) would be considered none to very mild. It is very unlikely that the levels of symptoms reported by aviators at the conclusion of this flight profile (110.4, 113.4, 113.9, and 114.4) would impact flight performance.

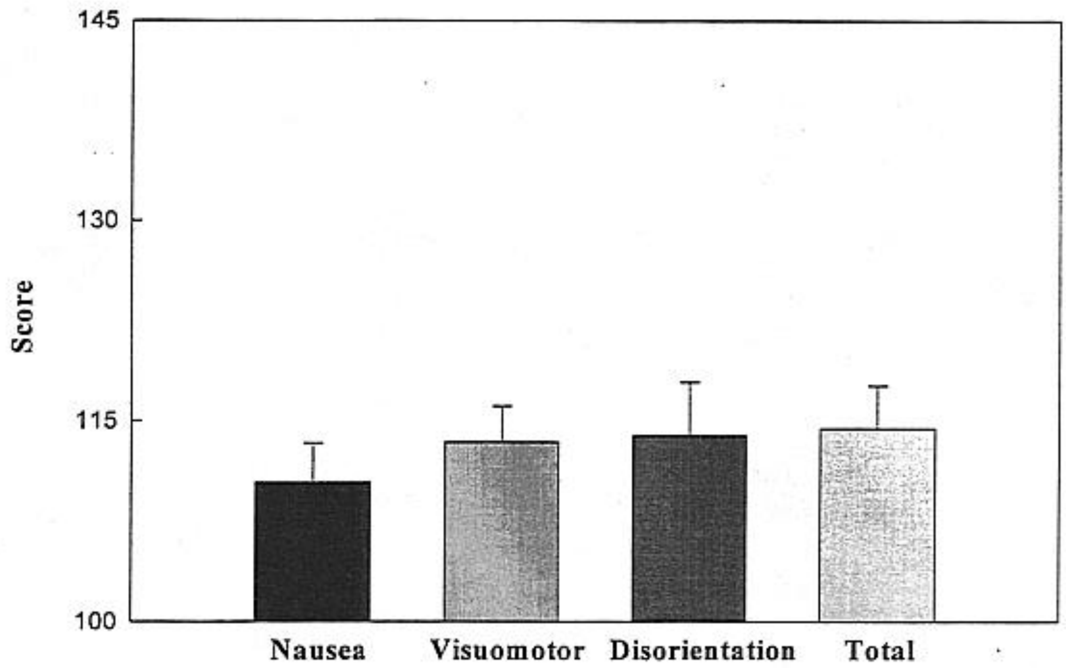

Figure 6. Effects of SD flight profiles on symptoms of simulator sickness.

<u>Summary</u>

The evaluation of this flight profile showed that the rates of visual and vestibular divergence used (4^0 per sec with pitch, 6^0 per sec with roll, and 8^0 per sec with drift) were enough to produce disorientation in the aviators. Of the 63 disorienting events presented (21 aviators; 3 events each), all interfered to some degree with pilot performance as seen in the reaction times of flight parameter recovery. On average, it took 54 seconds to recover from the pitch and roll and 122 seconds to recover from the drift. It is very likely that the recovery time for the drift was considerably longer than it was for the other two maneuvers because it is generally more difficult to reestablish the parameters for stationary flight than to correct deviations in-flight. While these recovery times may not seem extremely long, much can happen in a helicopter flying at 120 knots during the time span of 1-2 minutes.

Along with an objective measure of flight recovery (reaction time) following each SD event, a modified visual analog scale was used to obtain each aviator's subjective response. These two measures were poorly correlated suggesting that the aviators had a difficult time gauging how much the SD events disrupted their flight performance. Surprisingly, neither of these measures (reaction time or VAS) was influenced by the aviators' total flight time. We expected that pilots with a high number of flight hours would recover much quicker from the disorienting events than pilots with low flight time. However, our results showed that flight time was not related to how quickly pilots recovered from the pitch, roll, or drift events. There were also no significant correlations between flight time and the subjective responses to the SD events. Thus, flight time appears to be a very poor predictor of an aviator's response to disorienting events in this simulator flight profile.

The rates of visual and vestibular divergence used during the three SD events were not severe enough to produce total disorientation resulting in crashed aircraft (no aviator crashed the simulator as a result of the events) or simulator sickness. As mentioned earlier, these rates were considered slow to medium and it was not expected that they would produce degradations in flight performance due simulator sickness. Results from the SSQ given to each aviator at the end of the flight supported this position as symptoms were less than one standard deviation above the 100 mark (complete lack of symptoms).

Combining the visual and motion divergence software with the standard simulator programs did not produce any difficulties in standard data collection, retrieval, or analyses procedures. We were able to retrieve all the data from the standardized flight profile maneuvers and process it using existing programs. USAARL's Research Systems Branch did create several new specialized scoring routines which allowed us to examine the portions of the data containing the SD events.

As discussed in the background section, spatial disorientation can have disastrous effects when it happens to aviators in flight. It appears that this flight profile can be used as a new research tool by allowing us to more closely examine aviator response to disorienting events. Additionally, there are many stressors common to the aviation community such as fatigue, use of night vision devices, and thermal variations which may impact an aviator's response to a disorienting situation. This flight profile can be used to test the effects of these and other stressors on the response to disorientation in a controlled environment without putting aviators at risk.

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